

Water drops on high voltage transmission lines

Claudia Roero¹ and Timm H. Teich

¹ High Voltage Laboratory, Swiss Federal Institute of Technology,
CH-8092 Zürich, Switzerland
phone: (1) 0041-1-6327624
e-mail: croero@eeh.ee.ethz.ch

Abstract— Some high voltage lines emit annoying tonal noise when they are wet. It has been demonstrated that acoustical emissions have their origin in electrical discharges from deformed water drops on the lines.

The use of ultra-hydrophilic coatings and thus the reduction of the population of deformable water drops on the conductors by encouraging runoff and drying can provide a significant reduction of sound emissions produced by overhead high voltage transmission lines during and after wet weather conditions; the effects are particularly pronounced after the cessation of rain.

The work presented here is an electrical and optical investigation of the behaviour of drops on different high voltage conductors showing high framing rate records of their periodic deformation in the electric field. A technique to measure the drop size distributions which allows a geometric drop size classification at different times after the cessation of a rain period is proposed. It has been seen that the application of an electric field to the line yields an alteration of the drop size distribution, as drops of particular sizes may undergo resonant deformation. Discharges from the drops are also controlled by the drop geometry as drops of smaller contact angles with the substrate have higher corona inception voltages.

The combination of the study of the behaviour of the drops population and of the single drops deformation should support a method to predict the tonal emission from a specified high voltage transmission line.

I. INTRODUCTION

Acoustic emissions from wet high voltage lines can reach locally unacceptable levels and are linked to energy loss from the lines. Tonal noise at twice mains frequency ($2f = 100$ Hz) may cause particular annoyance while the common hissing or crackling noise is more readily tolerated and easier to suppress at the immission site. Both kinds of noise are associated with electrical

discharges from particular sites of elevated electrical field strength on conductors such as deformed water drops.

100 Hz oscillation of water drops on model conductors had been convincingly recorded in the laboratory [1] but it has been shown [2] that the mechanical motion on its own cannot quantitatively explain the 100 Hz emission. Nevertheless, water drop deformation in the electric field and associated Taylor instability can be instrumental in charge injection into the immediate surroundings of the conductors. This charge injection is subject to present investigation by electrical and optical means.

A major aim of current investigations is to have a tool for the prediction of noise levels (tonal and A-weighted) in dependence upon line/conductor configurations and meteorological conditions. After the cessation of rain the surface properties of the conductor control the lifetime of drops by influencing their shape, their retention, their runoff and conductor drying. Various formulations are under investigation. As the ensemble of water drops forms the most important discharge source and as drop oscillation and drop instability in the electric field depend on drop size, drop populations and their development are recorded to provide input data for the sound generation model.

II. SINGLE DROPS

Drop instability and discharge behaviour are intimately linked. Mechanical resonance frequencies are also connected with drop dimensions, furthermore also with contact angle. It has been previously shown [3], [4] that the global electric field strength causing drop instability and discharges at a given drop volume is more than halved when the contact angle increases from near 0° to 90° .

Drop resonances have been studied in a 10 mm parallel plate discharge gap configuration (120° Rogowski profile electrodes) by several different observation techniques (see also Tab.1):

1. “natural” drop oscillation to instability manifesting itself in repetitive Trichel pulse packets (DC) observed by current measurement.
2. Variable frequency AC excitation with optical observation at small amplitudes (resonances only just perceptible) and at large amplitudes leading to instability.
3. Optical observation of resonant drop breakup [5].

Resonant Taylor cone formation coincides with sequences of Trichel pulse [4] and [5] packets when the sessile drop is negative; the sequences cease eventually due to liquid loss from the drop which in turn is responsible for a consequential increase in inception voltage. Resonance frequencies inferred from the spacing of Trichel pulse packets from negative drops correspond well with those found with AC for large oscillation amplitudes near or at Taylor

cone occurrence and with a relatively hydrophilic substrate (contact angle $\approx 45^\circ$); they are also quite compatible with those measured by Corcoran

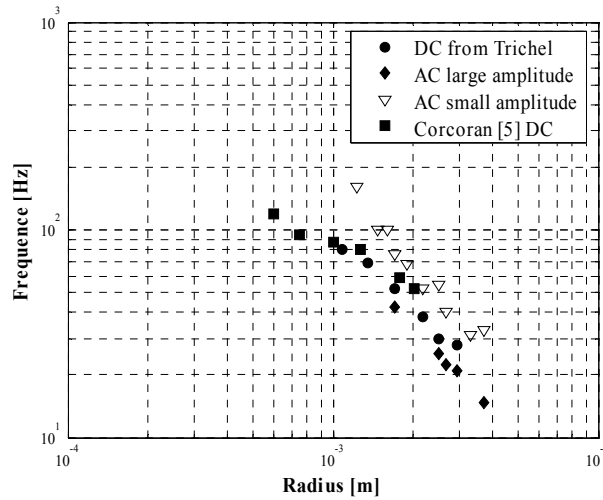


Fig. 1. Resonance frequencies of sessile water drops in DC and AC electric fields in dependence upon actual drop volume represented here in terms of a fictive radius which would be that of a *hemispherical drop* of just that volume. Very small amplitude *resonant* oscillation (∇) occurs at higher frequencies than large amplitude oscillation close to or at instability ($\bullet\blacklozenge\blacksquare$) which is tied up with discharges from the drop, that means with the process involved in sound emission. The small amplitude oscillations are irrelevant from point of view of sound emission.

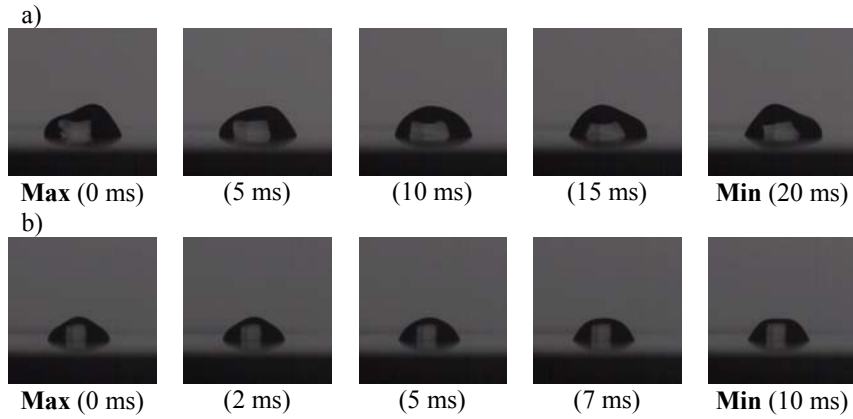


Fig. 2. a) Oscillation of a 100 μl water drop by an AC voltage of 25 kV. Distance time Max-Min is ~ 20 ms, i.e. the period of deformation is ~ 25 Hz b) Oscillation of a 50 μl water drops by an AC voltage of 27.5 kV. Distance Max-Min is ~ 10 ms, i.e. the period of deformation is ~ 100 Hz .

who observed the oscillation frequencies close to droplet breakup in a DC field (Fig.1 and Table 1).

TABLE 1: RESONANT OSCILLATION FREQUENCY [Hz] OF SESSILE WATER DROPS AGAINST RADIUS AND VOLUME

V [μ l]	Hemisph. radius [mm]	DC from Trichel pulse [Hz]	AC large ampl. $\alpha \approx 45^\circ$ [Hz]	AC small ampl. $\alpha \approx 90^\circ$ [Hz]	DC Corcoran drop destruction [Hz]
0.45	0.60	-	-	-	120
0.88	0.75	-	-	-	95
2.09	1.00	-	-	-	87
2.60	1.08	81	-	-	-
4.00	1.23	-	-	160	-
4.30	1.27	-	-	-	80
5.00	1.35	69	-	-	-
7.00	1.48	-	-	100	-
8.56	1.60	-	-	100	-
10.00	1.71	52	44.6, 40.2	85/68	-
12.00	1.79	-	-	-	59
15.00	1.91	-	-	68	-
17.20	2.02	-	-	-	52
20	2.17	38	-	52	-
30	2.50	30	25.3	54	-
40	2.68	-	22.4	40	-
50	2.95	28	21	-	-
70	3.30	-	-	31	-
100	3.70	-	14.8	33	-

With larger volume drops (20...100 μ l) higher mode oscillations are also observed: they take the form of a see-saw motion. Selected frames from a 1000 fps sequence are presented in Fig.2. Clearly the voltage at which the higher modes of oscillation occur depends on the drop size. In fact a higher voltage value (typically ≥ 25 kV_{rms} on a 30 mm gap) is needed if the drop is small.

III. DROPS STATISTICS ON HIGH VOLTAGE LINES

In order to set up a model which satisfactorily represents the population of the droplets on conductors, observations and evaluations of the behaviour of drop number and size as function of time and surface properties have been carried out.

A. Experimental setup and procedure

In the high voltage laboratory 150 cm long tubular model conductors of 10 mm radius and of different surface conditions (untreated, hydrophobic and hydrophilic) were set up with a distance of 74 cm from the ground. With an applied voltage of 100 kV, this corresponds to an electric field strengths on the surface of $20 \text{ kV}_{\text{eff}}/\text{cm}$. The centre section of the model conductors has been exposed to deionised water sprayed from a nozzle, typically at the rate of 100 mm/h representing heavy rain, for 5 minutes followed by a drying period of 25 minutes. Diagnostics included optical observation of deformation of water drops on the conductors by means of a high speed camera capable of up to 10 000 frames/sec, recording of change of drops population using a web-cam with 1 picture/min and sound pressure level detection with third-octave band filter centred on 100 Hz.

B. Measurements and considerations

To find out automatically number, size and associated distribution of the drops which remain on the conductors during and after the rain period, a Matlab script has been implemented. The program mentioned needs as input high-quality pictures of droplets; this condition has been properly met only by means of adding a fluorescent substance and illumination by a UV source.

The pictures and relative statistical distribution of drops on an untreated conductor before and after one minute high voltage application ($20 \text{ kV}_{\text{eff}}/\text{cm}$) are presented in Fig. 3. The statistical distribution of drop sizes on the conductor shows a significant reduction particularly of the number of small drops. For this investigation pictures have been recorded from the top with the web-cam positioned 2 m above the conductor.

Drops behaviour and acoustical emission at different time after the cessation of the rain period are presented in Fig. 4. Pictures have been recorded from the side using the high speed camera. Measurements on different surface states show different appearance and persistence of water drops and thus different decay characteristics of acoustical noise after rain.

A typical time history of acoustic emissions (100 Hz) for four different surface conditions is plotted in Fig. 5.

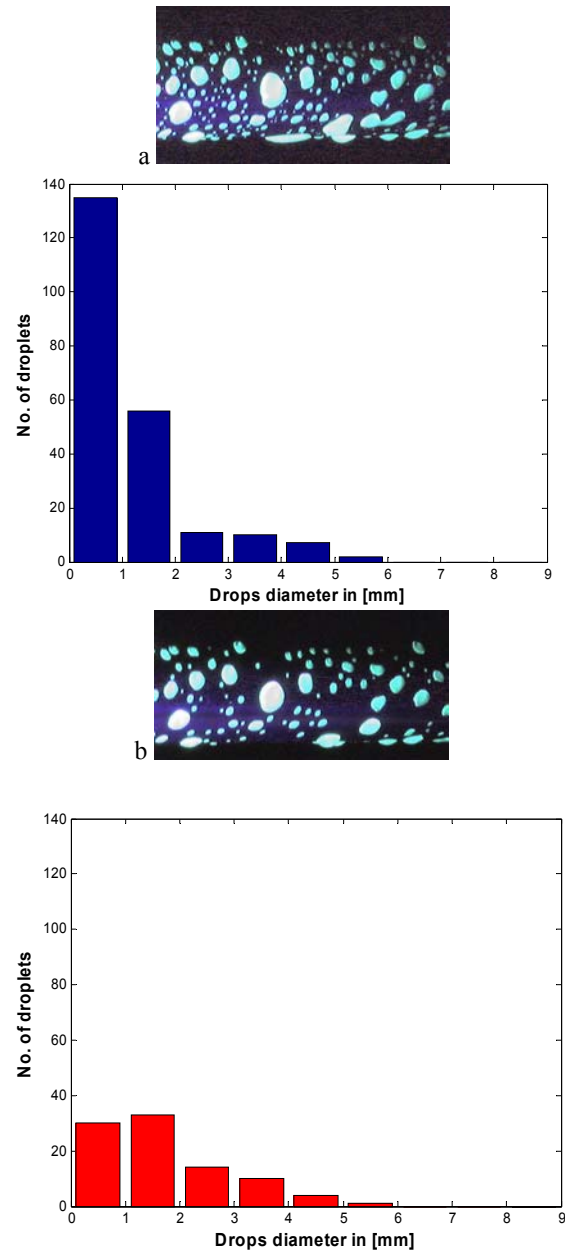


Fig. 3. Drop distribution on an untreated conductor before (a) and after (b) exposure to high voltage for 1 min only

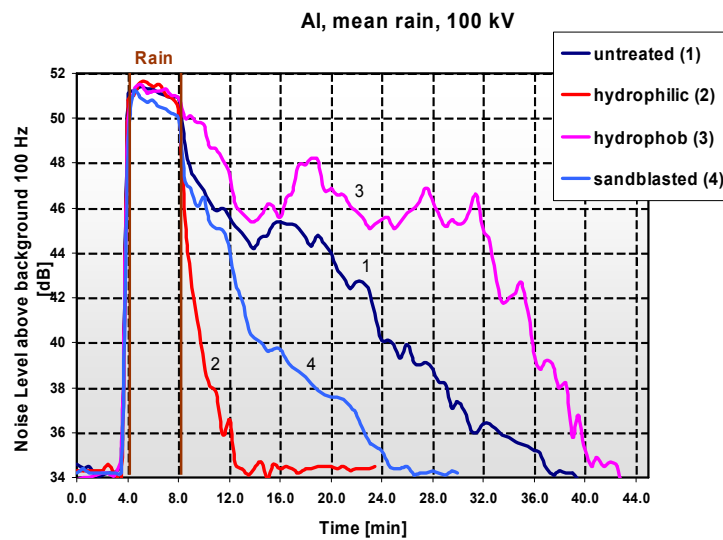
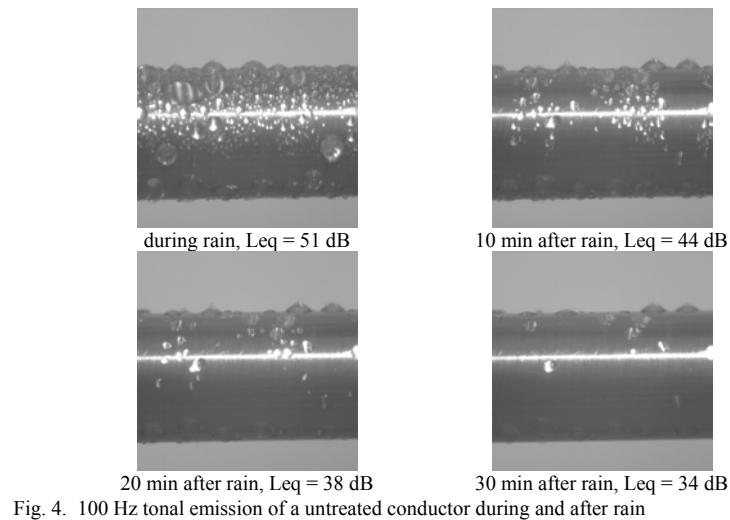


Fig. 5. Decay of sound level after the cessation of rain at $t = 8'$ for an Al tube with different coatings/treatments.

To assess dependence of acoustical emissions during and after rain on surface properties, a series of surface preparations (untreated, hydrophilic coated,

hydrophobic coated and sandblasted) on aluminum and on stainless steel have been analyzed. As example the case of the 20 mm diameter Al tube is presented in Fig. 5. All the results refer to 4 minutes rain, rate 100 mm/h. The sound decay with the hydrophobic conductor is much slower at 100 kV (20 kV_{eff}/cm) than is found with lower voltages. An explanation could be that at the higher voltage a larger number of small droplets go into instability. With the sandblasted conductor one can observe a considerable noise reduction during the rain period as the wettability changes with the amount of rain, which has flowed over the surface to the underside of the conductor. The hydrophilic conductor shows a remarkably rapid disappearance of sound emission.

IV. SUMMARY AND CONCLUSIONS

1. The oscillation frequency of water drops of different radius has been recorded using different observation techniques.
2. A useful program to find drop size distribution automatically has been developed.
3. Application of an electric field to the high voltage conductors produces a significant decrease of the drop number, particularly as far as small drops are concerned.
4. Highly hydrophilic coating promotes the drying of the conductors after rain, thus rapidly reducing the population of deformable water drops.

ACKNOWLEDGMENT

The support of the work by EnBW (D), APG (A), Illwerke AG (A), PSEL (CH) and BUWAL (CH) is greatly appreciated, and so is the continued interest of Prof. Klaus Fröhlich. The authors wish to thank M. Semmler and U. Straumann for comments and assistance.

REFERENCES

- [1] T. H. Teich and H-J Weber, "Tonal emission from high voltage lines", Proc. of 14th Int. Conf. on Gas Discharges and Their Applications, Liverpool, UK, 2002, Vol. 1, pp. 259-262.
- [2] U. Straumann and M. Semmler, "About the mechanism of tonal emission from high voltage lines", Proc. of 15th Int. Conf. on Gas Discharges and Their Applications, Toulouse, France, 2004, Vol.1, 363-366.
- [3] C. Roero "Contact angle measurements of sessile drops deformed by a DC electric field" Proc. of 4th International Symposium on Contact Angle, Wettability and Adhesion, Philadelphia, USA, 2004
- [4] C. Roero, T. H. Teich and H-J. Weber, "Mechanical and associated discharge behaviour of sessile water drop", Proc. of 15th Int. Conf. on Gas Discharges and their Applications, Toulouse, France, 2004, Vol.1, 335-338.
- [5] M. Corcoran, J. A. Bicknell, "Behaviour of water drop in a uniform electric field", Private communication and report, 2001.